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The Effect of Subsoiling on Crop Production in Saskatchewan

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The effect of subsoiling on crop production in Saskatchewan

M.C.J. Grevers
Saskatchewan Institute of Pedology
University of Saskatchewan

Abstract

The effect of deep tillage on crop production was evaluated, and involved 14 farm-cooperators, located in the Brown, Dark Brown, Black and Dark Gray soil zones.

Deep tillage improved crop production only on soils which had a hardpan layer. The improved crop growth resulted from the disruption of the hardpan layer, which allowed better water penetration, and also resulted in better use of soil water by the crop.

Deep ripping resulted in the largest improvements, which lasted up to three years, compared paraplowing, where the effects were less dramatic, and lasted only one year. On non-hardpan soils, deep tillage did not result in improved crop production.

There was no effect of deep tillage on soil salinity or soil sodicity (soluble sodium) for any of the soils. Work is in progress to formulate a set of recommendations on the feasibility of subsoiling in Saskatchewan, which includes the analysis of costs and benefits.

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Saskatchewan Institute of Pedology
University of Saskatchewan

Summary

Subsoiling was evaluated in terms of the effect on soil structure and crop growth over a 4-year period. A total of 14 farm-cooperators were involved, who allowed their soils to be deep ripped and/or paraplowed to depths varying from 35 to 75 cm (14 to 30 inches). The sites were located in the Brown, Dark Brown, Black and Dark Gray soil zones.

Subsoiling improved crop production only on Solonetzic soils, which have an impermeable layer (hardpan) close to the surface. The improved crop growth was found to have resulted from the disruption of the hardpan layer, which allowed for better water penetration from rainfall and/or snow melt, and also resulted in better use of soil water reserves by the crop during the growing season.

Of the two subsoiling operations, deep ripping had resulted in the largest improvements, which lasted up to three years. The effect of paraplowing on improved crop production was less dramatic, and lasted only one year. On non-Solonetzic soils, which do not have a hardpan layer, subsoiling did not result in improved crop production.

There was no effect of subsoiling on the levels of soil salinity (EC.) and soil sodicity (SAR., % water soluble sodium) for any of the soils, except for one soil. At Tisdale, the SAR. in the top 30-cm of the soil in the deep ripped area of the field was higher than that in the control and in the paraplowed areas of the field. The increased level of sodium in the top 30-cm depth would indicate that either significant amounts of sodic subsoil had been mixed in with the topsoil during deep ripping, or that water movement towards the soil surface by capillary rise had resulted in transporting sodium to the surface layers of the soil. Work is in progress to formulate a set of recommendations on the feasibility of subsoiling in Saskatchewan, which includes the analysis of costs and benefits.

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Saskatchewan Institute of Pedology
University of Saskatchewan

Technical Report

Deep tillage has received much attention in the media over the past 4 to 5 years. Articles have appeared in farm publications such as Country Guide (November 1984) and GRAINEWS (September 1986), which indicated that with deep ripping crop production had been increased at particular farm sites. Furthermore, farmers have frequently reported on improved crop production in parts of their field following the installation of pipelines. In Saskatchewan, soil disturbance from the installation of pipelines has been found to increase soil productivity of Solonetzic soils (de Jong and Button, 1973). There has been much discussion amongst the farm community in Saskatchewan regarding the deep tillage work in Alberta, such as on so-called "alkali soils" around Vegreville. Deep tillage in general is not recommended as a farm practice in Saskatchewan, particularly in areas sensitive to soil erosion and in areas with soil salinity problems. There was thus a need to investigate the feasibility of deep ripping under Saskatchewan conditions.

Deep tillage is defined as "a primary tillage operation which manipulates the soil to a greater depth than normal plowing" (American Society of Agricultural Engineers, 1971). Deep tillage or subsoiling is generally carried out to improve unfavorable characteristics of the subsoil such as plow pans and/or compacted layers (Russell, 1973). There is little evidence to suggest that soil compaction limits crop production in Saskatchewan (McConkey, 1987). On the other hand, solonetzic Bnt horizons have been found to severely limit crop production. These layers effectively reduce water infiltration into the soil, and subsequently reduce the amount of soil-water recharge over the winter period. In

dry years, solonetzic "pockets" in a field are the first areas showing a crop under severe water stress.

Deep tillage of Solonetzic soils has resulted in increased crop production in Alberta (Toogood and Cairns, 1978). Deep plowing of Solonetzic soils results in both the disturbance of the impermeable layer, and the mixing of the Na-rich Bnt horizon with the Ca-rich C horizon. Generally, the physical and chemical properties of these deep plowed Solonetzic soils are greatly improved (Cairns and Bowser, 1977). Much of the research on deep plowing of Solonetzic soils has been done in Alberta (Cairns, 1961, 1962; Bowser and Cairns, 1967). In Saskatchewan, Ballantyne (1983) studied soil conditions and crop production following deep plowing of Solonetzic soils north of Radville (near Weyburn). He found that the improved soil chemical conditions and crop growth from deep plowing persisted at least 5 years following deep plowing

Deep ripping is considerably less expensive than deep plowing, but may cause insufficient mixing of soil layers to result in significant improvement in the productivity of Solonetzic soils (Alzubaidi and Webster, 1982). Bole (1986) found increased soil-water infiltration following deep ripping, however, the effect only lasted for 2 years. Alzubaidi and Webster (1982) found that deep ripping had resulted in increased deep leaching of salts. There has been little evidence to suggest that deep ripping results in considerable increases in crop yield of Solonetzic soils (Lavado and Cairns, 1980). Lickacz (1986) reported that deep ripping of Solonetzic soils was less beneficial in terms of increasing crop production in areas with severe moisture deficits, than in "wetter" areas. For example, he reported average wheat yield increases due to deep ripping of 130 kg/ha in the Brown soil zone compared to 400 kg/ha in the Dark Brown and Black soil zones.

Deep rippers or subsoilers, are used to loosen the soil without inverting it, and are used primarily to break through and shatter compact sub soils. Under most conditions

subsoilers will break out a slot of soil that is slightly wider that the tool point (Cooper, 1971). The loosened soil resembles a triangular shaped trench (Bowen, 1981; Trouse and Humbert, 1959). Another type of subsoiler is the paraplow, which has been described as a "slant legged soil loosener" (Pidgeon, 1982). This tillage implement was originally designed to alleviate soil compaction in zero-tilled soils (Davies et al, 1982). Soil loosening is achieved through a lifting action along the legs of the plow, which results in the formation of cracks along natural planes of weakness (Davies et al, 1982). Soil loosening apparently is almost uniform with depth (Ehlers and Baeumer, 1988). Therefore, soil loosening with the paraplow is quite different from that with conventional subsoilers or deep rippers, where the soil is displaced forwards, sideways and upwards, leaving a V-shaped trench.

The objective of this research project was to investigate the effect of deep ripping and of paraplowing on the physical and chemical conditions of the soil and on crop production. A range of soil types were included, such as soils with varying degrees of Solonetzic characteristics, with different textures and in different soil zones. The investigation was carried out over a three year period.

Materials and Methods

A total of 12 farm sites are included in the study, involving both deep ripping, ranging in depth from 50 cm to 76 cm and paraplowing to a depth of 50 cm (Table 1). The sites involve both Solonetzic and Chernozemic soils, representing the Brown soil zone, the Dark Brown soil zone, the Black soil zone and the Dark Gray soil zone. In all cases deep ripping and paraplowing were carried out in the fall. On the majority of sites deep ripping was done with a KELLO-BILT subsoiler, pulled with a 1150 VERSATILE tractor (450

HP). Paraplowing was done with a HOWARD 3-bottom paraplow (courtesy of Agriculture Canada @ Swift Current). The paraplow was pulled with a DEUTSCH DX130 tractor (~120 HP) for most of the sites. At Tisdale, A BELARUS tractor (~250 HP) was used. At most sites, tillage strips were a 1/2 mile in length and 40' to 60' in width. The treatments were replicated three times. The strips were separated by a control area of similar dimensions. Secondary tillage operations, such as discing and harrowing to smooth down the deep-tilled fields were considerable, in particular at the Tisdale and Arborfield sites. At the Morgan farm, large depressions were left in the field, with subsequent exposed subsoil in some areas. At the Cragg and Chabot farms, subsequent secondary tillage operations in the spring had left the top 4" to 5" of the soil in a very dry and powdery condition for seeding.

Soil chemical criteria used to differentiate Solonetzic soils from Chernozemic soils are the exchangeable Ca/Na ratio and the % water soluble Na. A soil is considered to be solonetzic if the exchangeable Ca/Na ratio of the B horizon is equal to or less than 10 (Canada Soil Survey Committee, 1978). A Solonetzic soil can also be identified, if the % water soluble Na in the B horizon is equal to or greater than 50% (Ballantyne and Clayton, 1962). Based on soil chemical criteria, 5 of the sites (Boxall, Morgan, Cragg, Warner and Harrington) are solonetzic, satisfying either the criteria for the exch. Ca/Na ratio for the B horizon or the % Water Soluble Na (Table 2). A further 2 sites (McEwen and Chabot,) have at least one of the 6 sampled profiles (worst profile) that classifies as "chemically" being solonetzic. The remaining 5 sites (Rice, Norrish, Foisy, Jessiman and Millar) are non-solonetzic, and deep tillage is therefore not expected to improve crop production.

Soil physical parameters that were measured include soil moisture, soil bulk density and soil strength. Soil water content was measured by neutron thermalization, using a DEPTH MOISTURE GAUGE (Troxler Electronic Laboratories Inc.). Soil bulk density

was measured by gamma backscattering using a DEPTH DENSITY PROBE (Nuclear Chicago). A DEPTHPROBE CPN 501 (Hoskins Scientific) was used in 1988 for both the soil moisture and density readings. The scanning zone of the DEPTH DENSITY PROBE (Nuclear Chicago) has a vertical dimension of approximately 23 cm, while the scanning zone with the DEPTHPROBE CPN 501, has a vertical dimension of approximately 15 cm and is therefore more sensitive to "picking up" dense layers in the soil. Aluminum access tubes (2 per replicated plot) had been installed to a depth of 120 cm to facilitate the measurements of the soil bulk density and the soil moisture content in-situ, using the depth probes. Readings were taken prior to seeding (1 to 2 weeks) and at harvest time. Soil strength was measured with a Proctor penetrometer. This method involves pushing a probe into the soil and measuring the force required to do so. Penetrometer measurements were taken at the time of harvest at each crop sampling area.

Crop yield was determined by taking square meter samples, in a series of paired row samples, 6 pairs in each tillage strip. The samples were then transported to the University, where the samples were dried, weighed, threshed and analyzed for % nitrogen, by the Semi-Micro Kjeldahl method. Crop water use (mm) was determined from the difference between the soil moisture content at seeding and at harvest, plus the growing season precipitation (from the nearest weather station). Crop water-use efficiency was determined by dividing the grain yield by the total crop water use (kg/ha/cm).

Results and Discussion

Soil Bulk Density

The soil bulk density in the deep tillage plots in the spring of 1988 is listed in Table 3. The bulk density in 1987 was also measured, however, the instrumentation used in 1987

prevented the detection of small differences in density. The ripped plots were less dense and therefore had greater soil porosity at the 20-40 cm depth. In some cases (Boxall, McEwen and Morgan) this phenomena exists 3 years after the deep ripping operation. The density in the deep ripped plots compared to the control plots was lower by an average of 0.132 gm/cm^3 at the 25 cm depth, and by an average of 0.089 gm/cm^3 at the 40 cm depth. Comparable values for the paraplowed plots were 0.077 and 0.050 gm/cm3 for the 25 cm and for the 40 cm depths, respectively. The effect of paraplowing on soil bulk density was therefore less dramatic than the effect of deep ripping.

Soil-Water Recharge

Over-winter soil-water recharge was calculated from the soil moisture readings taken at harvest time (Aug/Sep) and in spring (April). The relative amount amount of soil-water recharge during this period therefore is indicative of differences in soil-water infiltration from rainfall and from melting snow, and of soil-water conservation during this period. The relative gain (cm H2O) in soil moisture in the deep tillage plots compared to the gain in soil moisture in the control plots for the first three years following the deep tillage operations is listed in Table 5. The ripped plots gained an additional 0.8 cm and 0 cm, in the second and in the third year, respectively, following deep ripping. No measurements had been taken for the first year. The paraplowed plots gained an additional 3.4 cm and 1.2 cm, in the first year and in the second year, respectively, following the paraplowing operations. There does appear to be a positive effect of either deep tillage treatment on soil-water recharge over the winter period, and the effect may last up to 2 years.

Soil Strength

Soil penetrometer measurements were taken at the time of harvest and results are shown in table 7. In 1986, the soil strength in the deep ripped plots at 7.5 cm depth was less than the soil strength in the control plots for all the three sites. The soil moisture

content at this depth (not shown) was also greater in the ripped plots. Consequently the differences in soil strength do not necessarily indicate differences in soil porosity. In 1987, there were two sites where deep ripping had resulted in reduced soil strength (Morgan and Jessiman), and two sites where paraplowing had reduced soil strength (Boxall and Jessiman). The soil moisture contents for these sites was similar amongst the tillage plots. In 1988, a more thorough investigation of soil strength with depth, revealed very little significant differences due to either deep ripping or due to paraplowing, except at the Tisdale sites at the 40 cm depth. In general, a trend in the data showed that deep ripping had reduced soil strength at the 20 and 40 cm depths, while paraplowing had reduced soil strength primarily at the 20 cm depth.

Crop Production

Crop growth was monitored during the growing season and harvest samples were taken one week prior to the farmer swathing the field (Table 7). Deep ripping resulted in significant yield increases on 4 of the 5 Solonetzic soils and on 1 of the 2 mixed Solonetzic/Chernozemic soils. There were no significant yield increases due to deep ripping on the 5 non-Solonetzic soils. Paraplowing significantly increased crop yield at only 2 sites, which were solonetzitc and mixed Solonetzic/Chernozemic soils. There were considerable plant emergence problems at some of the Solonetzic soils in the first year following deep tillage. Secondary tillage operations in the spring, required to "smooth down" the seedbed in the ripped strips, had resulted in relatively poor seedbed conditions (dry and loose). Seeding was carried out without adjusting for the different seedbed conditions that existed in the ripped strips. Crop emergence in the ripped areas was uneven and often delayed.

Crop response to strips of fertilizer nitrogen (30 and 60 kg/ha of N as 34-0-0) in 1988, was negligible in terms of crop yield and in terms of nitrogen content in the

harvested material. Percent protein in the harvested crop was not significantly affected by either deep ripping or by paraplowing.

Soil NO_3-nitrogen levels in the spring

Soil NO_3-N levels in the spring were significantly ($P < 0.05$) higher in the deep ripped and in the paraplowed plots. Mean values for all the plots were: 62.2 kg/ha and 50.4 kg/ha of N in the comparison of deep ripped and control plots involving 13 sites, and 70.0 kg/ha and 51.2 kg/ha of N in the comparison of paraplowed and control plots involving 5 sites. In the spring of 1989, the NO_3-N levels in the deep ripped plots were an average of 35 kg/ha greater than in the control plots, while the NO_3-N levels in the paraplowed plots were similar to those in the control plots The above indicates more favorable conditions for nitrogen mineralization from organic matter and/or less favorable conditions for denitrification in the deep tilled plots, since fertilizer applications were similar as well as N removal by previous crops.

Water-use efficiency

The water-use efficiency values for the 1988 crop are listed in Table 8. The average water-use efficiency for all the crops was 59 kg/ha/cm for the control plots and 72 kg/ha/cm for the ripped plots. These values are similar to the 1987 crop values of 67 kg/ha/cm for the control plots and 76 kg/ha/cm for the ripped plots. The increase in water-use efficiency due to deep ripping may be due in part because of higher soil NO_3-N levels in the spring as earlier indicated. Other factors such as improved water penetration and root proliferation may have also played a role, however, they were not measured as such. The effect of paraplowing on crop water-use efficiency was measurable at only one site, at McEwen, where paraplowing increased the W.U.E. from 65 kg/ha/cm to 90 kg/ha/cm.

Crop production over the three year period following deep tillage.

There were considerable plant emergence problems in the first year after deep ripping at 6 sites; Boxall, McEwen, Morgan, Cragg, Chabot and Norrish. In each case spring secondary tillage operations required to "smooth down" the seedbed in the ripped strips, had resulted in relatively poor seedbed conditions. In 1986, timely spring rains alleviated the crop emergence problems at the Boxall, McEwen and Morgan sites. The crop in the ripped areas recovered and eventually out-yielded the crop in the control areas at these sites. In 1987, rainfall was relatively poor in the spring, and the crop in the ripped areas at Cragg's and at Chabot's was unable to fully recover, and as a consequence some of the crop never emerged and some of the crop was still quite green at the time of harvest. The same problems existed in 1988 at the Norrish site.

Deep ripping increased crop yields mainly on Solonetzic soils. In the first year following deep ripping, yield increases due to deep ripping were 26 % at Boxall, 16 % at Morgan, -20% at Cragg, 26 % at J.Eliason, and 58 % at Warner. In the second year following deep ripping, yield increases were 89 % at Boxall, 18 % at Morgan, and 49 % at Cragg. In the third year following deep ripping, there was a yield increase of 33% at Morgan, while at Boxall no crop could be harvested. In the mixed Solonetzic-Chernozemic soils, deep ripping improved yields only at one site, McEwen, where yield increases were 45 %, 14 %, and 35 %, in the first, in the second and in the third year, respectively, following deep ripping. At the other 3 sites (Chabot, Riopka and D.Eliason), there was no significant effect of dep ripping on crop yield. There was no significant effect of deep ripping on crop yield in any of the non-Solonetzic soils (Rice, Jessiman and Norrish).

Soil salinity and sodicity levels in the subsoiled and controls plots

Subsoiling has been shown to increase leaching of soluble salts (Bole 1986), by increasing the hydraulic conductivity of the surface layers of the soil. In this study,

subsoiling had resulted in increasing the porosity of the B horizon and ,consequently, the possibility existed for increased leaching of soluble salts in the subsoiled plots. However, the amount precipitation was low for much of the period following the subsoiling. The levels of soil salinity (E.C.) and soil sodicity (S.A.R. and % water soluble sodium) for the sites are shown in Table 9. There were no significant differences ($P<0.05$) between the means of the treatments for any of the sites and for any of the depths, except for the Tisdale soil. At Tisdale, the level of soil sodicity (S.A.R.) in the top 30-cm in the deep ripped part of the field had increased relative to that of the control. It is possible that sodium rich subsoil was brought to the surface during deep ripping, as deep ripping resulted in a substantial amount of soil mixing at this site. However, it is more likely that soil-water movement to the surface was enhanced by the deep ripping. This would explain the large difference in crop water-use efficiency reported for the 1987 crop (Grevers 1988), and the higher level of soil NO_3-nitrogen reported earlier. Presumable NO_3, leached in previous years, when dissolved in soil water, would move towards the soil surface. In a similar manner, the soluble sodium salts could move to the soil surface. Normal amounts of precipitation for this area will probably reverse the above.

Conclusions

A total of 12 sites were included in the study involving 4 different soil zones. Based on soil chemical criteria, the sites include 6 Solonetzic soils, 4 mixed Solonetzic-Chernozemic soils, and 5 non-Solonetzic (Chernozemic) soils. The deep tillage operations involved deep ripping and paraplowing, which had been carried out in the fall.

By the spring of 1988, the soils in the deep ripped plots were less dense in the 25-40 cm depth. The soils in the paraplowed plots were also less dense at these depths,

however the differences were less dramatic. The same pattern was found in terms of soil strength.

Both deep ripping and paraplowing increased soil water recharge for up to two years following the deep tillage operation.

Crop emergence at some sites was decreased in the tillage plots, due to poor seedbed conditions, created as a result of the secondary tillage operations in spring that were required to smooth down the soil surface. In some cases poor emergence resulted in reduced yields.

Soil NO_3-nitrogen levels in the spring of 1988 and of 1989, were significantly greater in the ripped plots compared to the control plots, and in the paraplowed plots soil NO_3-nitrogen levels in the spring of 1988 were significantly greater compared to the control plots.

Deep ripping resulted in significant yield increases on 4 of the 5 Solonetzic soils and on 1 of the 2 mixed Solonetzic/Chernozemic soils. There were no significant yield increases due to deep ripping on 5 non-Solonetzic soils. Paraplowing significantly increased crop yield at 2 sites, which were either Solonetzic or mixed Solonetzic/Chernozemic. There was little effect of either deep tillage treatment on the percent protein in the crop, nor was there a significant response in terms of crop growth to different rates of nitrogen fertilizer levels. Deep ripping had increased the water-use efficiency by an average of 22%.

Results from three years of data indicate that crop yield was significantly increased due to either deep ripping or paraplowing on Solonetzic soils. Increases were more dramatic following deep ripping than following paraplowing. The yield increases lasted at least two years following the deep tillage operations, and at two sites the yield increases

lasted into the third year. Deep ripping and paraplowing did not increase yields on non-Solonetzic soils.

Subsoiling had very little effect on the level of soluble salts or on the level of water soluble sodium in either the Chernozemic or Solonetzic soils. One exception was a Solonetzic soil at Tisdale, where the level of sodium in the top 30-cm had increased as a result of deep ripping.

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Table 1. Soil description and tillage details of the research plots

Site	Farm	Soil Zone	Soil Order	Soil Association	Year of Tillage	Depth of tillage
			Deep Ripped			(cm)
Tisdale	Boxall	D.Gray	Solonetz	Arborfield C-CL	1985	76
	McEwen	D.Gray	Solon/Chern	Arborfield C-CL	1985	76
	Morgan	D.Gray	Solonetz	Arborfield C	1985	76
	Rice	D.Gray	Chernozem	Tisdale SiC-SiCL	1986	76
Arborfield	Chabot	D.Gray	Solon/Chern	Arborfield C	1986	76
	Cragg	D.Gray	Solonetz	Arborfield C	1986	76
Carrot River	Norrish	D.Gray	Chernozem	Tisdale C	1987	61
	Warner	D.Gray	Solonetz	Arborfield C	1987	61
Lucky Lake	Jessiman	Brown	Chernozem	Sceptre HC	1986	50
Cut Knife	Foisy	Black	Chernozem	Oxbow L	1986	50
			Paraplowed			
Tisdale	Boxall	D.Gray	Solonetz	Arborfield C-CL	1986	50
	McEwen	D.Gray	Solon/Chern	Arborfield C-CL	1986	50
Glenside	Harrington	D.Brown	Solonetz	Tuxford C	1986	50
Lucky Lake	Jessiman	Brown	Chernozem	Sceptre HC	1986	50
Cut Knife	Foisy	Black	Chernozem	Oxbow L	1986	50
Birsay	Millar	Brown	Chernozem	Fox Valley CL	1986	50

Solon/Chern = mixed Solonetzic-Chernozemic

Table 2. Soil chemical characteristics of the B horizons of the deep tillage sites.

Site	Farm	Means of all the profiles		Worst profile	
		ECN†	PWSS‡	ECN†	PWSS‡
Tisdale	Boxall	5	31	3	40
	McEwen	19	43	14	57
	Morgan	2	68	1	71
	Rice	133	14	110	19
Arborfield	Chabot	30	46	17	53
	Cragg	7	9	6	81
Lucky Lake	Jessiman	231	10	118	15
Carrot River	Norrish	121	8	97	12
	Warner	4	59	3	74
Glenside	Harrington	35	44	1	63
Cut Knife	Foisy	28	10	22	12
Birsay	Millar	30	22	27	23

†. Exchangeable Calcium to exchangeable sodium ratio
‡. Percent water soluble sodium

Table 3. Soil bulk density values in the spring of 1988, for the 25,40 and 60 cm depths.

Site	Farm	25 cm		40 cm		60 cm	
		Cntl	Till	Cntl	Till	Cntl	Till
		gm/cm^3					
		Deep Ripped					
Tisdale	Boxall	1.419	1.311	1.489	1.425*	1.500	1.470
	McEwen	1.222	1.091	1.492	1.412*	1.542	1.508
	Morgan	1.310	1.228	1.503	1.403*	1.474	1.457
	Rice	1.147	1.137	1.689	1.477*	1.510	1.601
Arborfield	Chabot	1.286	1.048	1.442	1.330	1.495	1.505
	Cragg	1.428	1.297	1.383	1.256	1.425	1.465
Carrot Rvr	Norrish	1.479	1.312	1.456	1.422	1.446	1.419
	Warner	1.600	1.438	1.362	1.298	1.344	1.374
Lucky Lk	ssiman	1.399	1.083*	1.508	1.336*	1.573	1.568
Cut Knife	Foisy	1.384	1.476	1.701	1.687	1.835	1.684*
		Paraplowed					
Tisdale	Boxall	1.419	1.394	1.489	1.374*	1.500	1.470
	McEwen	1.226	1.275	1.422	1.374	1.504	1.509
Lucky Lk	Jessiman	1.399	1.257	1.508	1.454	1.573	1.578
Birsay	Millar	1.414	1.178	1.513	1.529	1.637	1.620

Values followed by * are significantly different $P<0.05$
No values are available for the Harrington and Foisy paraplowed sites.

Table 4. Over-winter water recharge in the tillage plots for 1987/1988.

Site	Tillage	Soil moisture levels			
		Fall	Spring	Gain	% Gain
		cm H_2O			
Boxall	Control	36.2	48.2	12.0	33
	Ripped	36.7	49.5	12.8	35
	Paraplowed	35.2	48.2	13.0	37
McEwen	Control	35.1	45.0	9.9	28
	Ripped	36.6	44.7	8.1	22
	Paraplowed	34.0	45.4	11.4	34
Morgan	Control	36.5	47.8	11.3	31
	Ripped	36.6	48.9	12.3	34
Rice	Control	27.6	35.0	7.4	27
	Ripped	23.8	30.0	6.2	26
Chabot	Control	40.7	50.7	10.0	25
	Ripped	36.8	46.9	10.1	27
Cragg	Control	37.8	52.6	14.8	39
	Ripped	36.6	53.1	16.5	45
Jessiman	Control	33.4	36.2	2.8	8
	Ripped	32.3	37.1	4.8	15
	Paraplowed	37.5	40.8	3.3	9
Millar	Control	25.2	27.8	2.3	9
	Paraplowed	25.6	29.8	4.2	16
Foisy	Control	21.8	24.4	2.7	12
	Ripped	22.6	24.0	1.4	6

No data available for the Harrington site

Table 5. Increase in soil water recharge in the deep tillage plots relative to that in the control plots for the first three years following the deep tillage operations.

Site	Year #1	Year #2	Year #3
	cm H_2O		
Deep Ripped			
Boxall	n.d.	0.0	0.8
Morgan	n.d.	4.0	1.0
McEwen	n.d.	1.0	-1.8
Rice	n.d.	-1.2	n.d.
Chabot	n.d.	0.1	n.d.
Cragg	n.d.	1.7	n.d.
Jessiman	1.8	2.0	n.d.
Foisy	-1.7	-1.3	
Average	n.d.	0.8	0.0
Paraplowed			
Boxall	2.8	1.0	n.d.
McEwen	5.5	1.5	n.d.
Jessiman	5.1	0.5	n.d.
Millar	0.0	1.9	n.d.
Average	3.4	1.2	n.d.

n.d. = no data available

Table 6. Soil strength measurements in the top 40 cm in the tillage plots.

Site	Tillage	1986	1987	1988			
		7.5 cm	7.5 cm	10 cm	20 cm	30 cm	40 cm
		MPa					
Boxall	Control	1.65	0.76	1.75	2.67	4.00	4.25
	Ripped	1.16	0.73	1.25	1.50	1.68	1.50
	Parapl.		0.64*	1.75	4.63	4.38	4.88
McEwen	Control	8.25		4.79	6.58	7.71	8.13
	Ripped	6.58		5.14	6.72	7.61	7.83
	Parapl.			4.94	6.36	7.44	7.67
Morgan	Control	7.35	2.93	3.38	4.38	5.46	6.25
	Ripped	3.46	2.04*	3.00	4.46	4.96	5.13
Rice	Control			1.67	2.75	3.97	5.94
	Ripped			1.36	2.03*	2.86	3.50*
Chabot	Control		0.39	6.97	7.22	8.19	8.28
	Ripped		0.38	6.47	7.14	7.94	8.03
Cragg	Control			5.61	6.36	6.94	7.28
	Ripped			4.92	5.78	6.33	6.67
Jessiman	Control		0.92	2.92	5.33	4.78	6.03
	Ripped		0.60*	2.56	3.53*	4.72	5.53
	Parapl.		0.75*	2.47	3.92	5.56	6.58
Norrish	Control			2.97	4.19	5.28	5.67
	Ripped			2.56	3.50	4.56	4.94
Warner	Control			5.44	5.56	4.89	4.94
	Ripped			4.25	4.83	5.06	5.46
Millar	Control		3.99	0.72	1.81	2.28	3.08
	Parapl.		4.96	0.64	1.44	1.94	2.53

Values followed by a * indicate significantly different from the value for the control

Table 7. Crop yield and yield variability in the tillage plots

Site	Year	Crop	Tillage	Yield	Coeff. of V.
				(Bu/A)	(%)
Boxall	1986	Wheat	Control	34.3 a	22
			Ripped	43.1 b	19
	1987	Wheat	Control	18.4 a	36
			Ripped	34.8 b	31
			Parapl.	29.5 b	31
	1988	Wheat	Crop Failure		
	1989	Wheat	Control	37.4 a	nd
			Ripped	42.1 a	nd
			Paraplowed	35.3 a	nd
McEwen	1986	Peas	Control	22.7 a	23
			Ripped	32.9 b	25
	1987	Flax	Control	21.0 a	12
			Ripped	24.0 a	8
	1987	Flax	Control	22.5 a	12
			Parapl.	23.1 a	7
	1988	Barley	Control	30.3 a	32
			Ripped	40.8 b	30
	1988	Barley	Control	25.0 a	26
			Parapl.	37.2 b	23
	1989	Flax	Control	11.5 a	nd
			Ripped	12.1 a	nd
	1989	Flax	Control	11.5 a	nd
			Paraplowed	10.0 a	nd
Morgan	1986	Barley	Control	48.6 a	22
			Ripped	56.5 b	20
	1987	Flax	Control	23.0 a	18
			Ripped	27.1 b	10
	1988	HY320	Control	14.3 a	30
			Ripped	19.0 b	30
	1989	HY320	Control	37.8 a	nd
			Ripped	43.3 a	nd
Chabot	1987	Peas	Control	31.2 a	17
			Ripped	28.6 a	29
	1988	Flax	Control	9.8 a	30
			Ripped	9.8 a	25
	1989	Summerfallow			

Table 7. Continued

Site	Year	Crop	Tillage	Yield	Coeff. of V.
				(Bu/A)	(%)
Cragg	1987	Wheat	Control	41.8 a	13
			Ripped	34.9 b	21
	1988	Barley	Control	23.8 a	28
			Ripped	35.4 b	12
	1989	Summerfallow			
Rice	1988	Wheat	Control	29.1 a	25
			Ripped	33.0 a	15
	1989	Flax	Control	14.4 a	nd
			Ripped	15.0 a	nd
Jessiman	1987	Wheat	Control	44.1 a	21
			Ripped	44.3 a	20
			Parapl.	46.4 a	21
	1988	W.Wheat	Crop Failure		
	1989	Barley	Control	30.9 a	nd
			Ripped	33.7 a	nd
			Paraplowed	30.2 a	nd
Harrington	1987	Wheat	Control	20.0 a	20
			Parapl.	19.8 a	22
	1988	Mustard	Crop Failure		
	1989	Summerfallow			
Foisy	1987	Lentils	Control	40.4a	12
			Ripped	41.1a	13
			Parapl.	42.3a	13
	1988	Peas	No Samples		
	1989	Canola	Control	16.6 a	nd
			Ripped	17.1 a	nd
			Paraplowed	18.4 a	nd
Millar	1987	Flax	Control	34.7 a	13
			Parapl.	35.0 a	10
	1988	Wheat	Control	35.5 a	38
			Parapl.	37.7 a	38

Table 7. Continued

Site	Year	Crop	Tillage	Yield	Coeff. of V.
Norrish	1988	Canola	Control	30.4 a	25
			Ripped	25.9 a	38
	1989	Canola	Control	25.7 a	nd
			Ripped	24.8 a	nd
Warner	1988	Canola	Control	12.8 a	20
			Ripped	20.2 b	29
	1989	Barley	Control	25.8 a	nd
			Ripped	61.1 b	nd

Values that are followed by the same letter are not significantly different at the P 0.05 level (ANOV of block means)

* Denotes significantly different from the "control" when analyzed as paired observations instead of ANOV of block means

nd = no data available at this time

Table 8. Water-use efficiency of the 1988 crop

Site	Farm	Crop	Tillage	Yield	Water Use	W.U.E.
				kg/ha	mm	kg/ha/cm
Tisdale	Boxall	Wheat	Control	292	169	17.3
			Ripped	396	167	23.8
			Parapl.	316	169	18.8
	McEwen	Barley	Control	1773	239	74.3
			Ripped	2393	243	98.6
			Control	1461	226	64.7
			parapl.	2173	241	90.1
	Morgan	HY 320	Control	1057	207	51.0
			Ripped	1405	224	62.8
	Rice	Wheat	Control	1080	181	59.5
			Ripped	1222	162	75.5
Arborfield	Chabot	Flax	Control	700	247	28.3
			Ripped	679	242	28.0
	Cragg	Barley	Control	1763	242	72.9
			Ripped	2619	256	102.4
Carrot River	Norrish	Canola	Control	1877	291	64.5
			Ripped	1640	291	56.3
	Warner	Canola	Control	788	306	25.8
			Ripped	1247	322	38.8

Other sites: Harrington and Jessiman had crop failure, Foisy had swath the crop before samples could be taken, J.Eliason & D. Eliason & Riopka & Millar had irrigated crops

Table 9. Soil chemical characteristics in the subsoiled plots at the end of the experiment

Farm	Tillage	Depth	W.S.S.	SAR†	EC‡	pH
		(cm)	(%)		mS/cm	
Millar	Paraplowed	0-15	26.0	1.23	1.27	7.3
Millar	Paraplowed	15-30	22.5	1.00	1.17	7.7
Millar	Paraplowed	30-45	45.5	2.30	0.90	8.2
Millar	Paraplowed	45-60	29.9	3.30	5.40	7.7
Millar	Control	0-15	36.2	1.53	0.77	7.2
Millar	Control	15-30	42.0	1.53	0.60	7.7
Millar	Control	30-45	58.3	3.57	0.97	8.2
Millar	Control	45-60	69.1	7.30	2.60	8.5
Harrington	Paraplowed	0-15	47.6	2.63	0.73	7.7
Harrington	Paraplowed	15-30	66.7	4.73	0.80	8.2
Harrington	Paraplowed	30-45	66.9	9.07	4.73	8.3
Harrington	Paraplowed	45-60	60.7	12.20	9.60	8.2
Harrington	Control	0-15	31.4	1.33	0.77	7.3
Harrington	Control	15-30	57.2	3.30	0.60	8.0
Harrington	Control	30-45	66.3	8.60	3.43	8.3
Harrington	Control	45-60	62.8	10.60	7.00	8.3
Jessiman	Paraplowed	0-15	9.5	0.33	1.13	6.7
Jessiman	Paraplowed	15-30	20.0	0.53	0.47	7.2
Jessiman	Paraplowed	30-45	38.7	1.23	0.40	8.0
Jessiman	Paraplowed	45-60	48.2	2.80	1.30	8.1
Jessiman	Control	0-15	10.1	0.27	0.50	7.3
Jessiman	Control	15-30	17.7	0.43	0.33	7.8
Jessiman	Control	30-45	37.5	1.03	0.37	8.0
Jessiman	Control	45-60	50.0	2.70	1.00	8.1
Jessiman	Ripped	0-15	10.8	0.27	0.40	7.1
Jessiman	Ripped	15-30	17.3	0.43	0.33	7.8
Jessiman	Ripped	30-45	33.2	1.00	0.37	8.0
Jessiman	Ripped	45-60	64.6	3.50	0.70	8.1
Foisy	Paraplowed	0-15	4.5	0.20	1.17	5.2
Foisy	Paraplowed	15-30	10.5	0.20	0.43	6.0
Foisy	Paraplowed	30-45	13.8	0.27	0.23	6.3
Foisy	Paraplowed	45-60	17.6	0.50	0.50	7.5
Foisy	Control	0-15	4.8	0.17	1.03	5.2
Foisy	Control	15-30	9.4	0.23	0.47	6.0
Foisy	Control	30-45	17.6	0.60	0.60	6.9
Foisy	Control	45-60	28.4	1.60	1.70	7.8

† Sodium Adsorption Ratio
‡ Electrical Conductivity

Table 9. Continued

Farm	Tillage	Depth	W.S.S.	SAR†	EC‡	pH
		(cm)	(%)		mS/cm	
Foisy	Ripped	0-15	4.7	0.17	0.90	5.0
Foisy	Ripped	15-30	10.5	0.23	0.50	6.0
Foisy	Ripped	30-45	19.0	0.57	0.60	6.9
Foisy	Ripped	45-60	42.5	1.50	0.50	8.1
McEwen	Paraplowed	0-15	20.3	0.60	0.73	5.6
McEwen	Paraplowed	15-30	43.1	1.40	0.43	6.5
McEwen	Paraplowed	30-45	51.8	2.93	0.73	7.7
McEwen	Paraplowed	45-60	56.2	4.60	2.10	8.0
McEwen	Control	0-15	17.4	0.73	1.48	5.5
McEwen	Control	15-30	42.7	1.63	0.63	6.7
McEwen	Control	30-45	51.2	3.00	0.98	7.5
McEwen	Control	45-60	52.5	4.50	2.50	7.9
McEwen	Ripped	0-15	22.9	0.97	1.43	5.3
McEwen	Ripped	15-30	57.9	2.47	0.47	6.5
McEwen	Ripped	30-45	56.2	3.80	1.57	7.7
McEwen	Ripped	45-60	35.8	4.10	5.20	7.8
Boxall	Paraplowed	0-15	21.6	0.83	1.17	6.1
Boxall	Paraplowed	15-30	39.5	1.47	0.60	7.2
Boxall	Paraplowed	30-45	50.2	2.83	1.13	8.0
Boxall	Paraplowed	45-60	39.0	4.80	5.55	7.9
Boxall	Control	0-15	29.4	1.32	1.42	6.4
Boxall	Control	15-30	44.8	1.96	1.02	7.0
Boxall	Control	30-45	57.7	4.12	1.72	8.1
Boxall	Control	45-60	49.6	7.40	6.90	8.0
Boxall	Ripped	0-15	43.8	2.83	1.73	6.9
Boxall	Ripped	15-30	51.5	3.10	1.20	7.1
Boxall	Ripped	30-45	52.0	5.43	4.07	8.0
Boxall	Ripped	45-60	51.7	8.10	7.20	8.0
Morgan	Control	0-15	69.2	5.70	1.15	5.9
Morgan	Control	15-30	80.6	7.95	1.15	7.2
Morgan	Control	30-45	77.1	10.70	4.00	8.2
Morgan	Control	45-60	70.0	10.80	5.00	8.1
Morgan	Ripped	0-15	63.5	4.60	1.50	5.6
Morgan	Ripped	15-30	78.7	6.55	1.05	6.6
Morgan	Ripped	30-45	81.9	10.70	2.50	8.2
Morgan	Ripped	45-60	60.0	10.90	8.10	8.1

† Sodium Adsorption Ratio
‡ Electrical Conductivity

Table 9. Continued

Farm	Tillage	Depth	W.S.S.	SAR†	EC‡	pH
		(cm)	(%)		mS/cm	
Rice	Control	0-15	10.5	0.43	1.10	6.6
Rice	Control	15-30	20.1	0.60	0.57	7.1
Rice	Control	30-45	21.7	0.60	0.43	7.6
Rice	Control	45-60	38.0	1.30	0.60	8.1
Rice	Ripped	0-15	8.7	0.30	0.97	6.5
Rice	Ripped	15-30	12.2	0.30	0.60	7.1
Rice	Ripped	30-45	20.2	0.57	0.43	7.8
Rice	Ripped	45-60	37.8	1.20	0.40	8.1
Chabot	Control	0-15	27.1	0.93	0.73	5.7
Chabot	Control	15-30	44.0	1.67	0.60	6.0
Chabot	Control	30-45	61.9	2.70	0.57	7.0
Chabot	Control	45-60	56.3	4.20	1.80	7.9
Chabot	Ripped	0-15	24.4	0.80	0.67	5.8
Chabot	Ripped	15-30	41.7	2.00	1.17	6.1
Chabot	Ripped	30-45	64.2	2.37	0.40	6.5
Chabot	Ripped	45-60	60.7	3.50	0.90	7.6
Cragg	Control	0-15	65.7	4.57	1.17	6.4
Cragg	Control	15-30	80.8	7.37	1.03	7.5
Cragg	Control	30-45	76.2	10.43	3.40	8.0
Cragg	Control	45-60	67.5	11.50	6.20	8.0
Cragg	Ripped	0-15	68.7	4.17	0.80	6.9
Cragg	Ripped	15-30	82.3	7.30	0.97	7.6
Cragg	Ripped	30-45	82.5	10.50	2.00	8.0
Cragg	Ripped	45-60	74.0	11.90	4.70	7.9
Norrish	Control	0-15	8.2	0.27	0.77	7.0
Norrish	Control	15-30	12.9	0.40	0.50	6.9
Norrish	Control	30-45	19.2	0.70	0.73	7.1
Norrish	Control	45-60	13.1	0.70	1.80	7.7
Norrish	Ripped	0-15	7.4	0.30	1.00	6.7
Norrish	Ripped	15-30	9.0	0.27	0.63	6.7
Norrish	Ripped	30-45	12.0	0.37	0.80	7.1
Norrish	Ripped	45-60	13.2	0.70	1.70	7.4

† Sodium Adsorption Ratio
‡ Electrical Conductivity

Table 9. Continued

Farm	Tillage	Depth	W.S.S.	SAR†	EC‡	pH
		(cm)	(%)		mS/cm	
Warner	Control	0-15	74.1	5.87	1.23	5.2
Warner	Control	15-30	74.3	7.30	1.67	6.3
Warner	Control	30-45	67.6	9.07	4.10	7.5
Warner	Control	45-60	60.8	9.60	6.20	8.0
Warner	Ripped	0-15	65.4	4.23	1.00	5.6
Warner	Ripped	15-30	79.5	6.97	1.13	6.1
Warner	Ripped	30-45	74.5	9.23	2.90	7.5
Warner	Ripped	45-60	56.5	8.30	5.90	7.9

† Sodium Adsorption Ratio
‡ Electrical Conductivity